TUNING INDICATORS AND AUTOMATIC FREQUENCY CONTROLS FOR RADIO RECEIVERS

31FR-1

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

PIONEER HOME STUDY RADIO SCHOOL
NRI

Study Schedule No. 31

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix important facts firmly in mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☐ **1. Making Receivers Easy to Tune; Current-Controlled Visual Tuning Indicators; Voltage-Controlled Visual Tuning Indicators - Pages 1-8**

Here is a wealth of practical information which you'll appreciate even more once you begin working on receivers which have tuning indicators. Give particular attention to the section on cathode ray tuning indicators, because you will encounter these more than any other types. Answer Lesson Questions 1, 2 and 3.

☐ **2. Unique Tuning Aids; Essential Sections of an A.F.C. System; The Discriminator Circuit - - - - - - - - - - - - - - Pages 8-13**

Here we have brief but interesting descriptions of one-of-a-kind tuning indicators which are to be found on only a few models of receivers. One reading now will be enough, because you can always refer to this section later. Study thoroughly every bit of the information on a.f.c. systems, however, because this basic information applies also to f.m. receivers. Answer Lesson Questions 4, 5 and 6.

☐ **3. Review of Phase; Discriminator Circuit Action; The Oscillator Control Circuit - - - - - - - - - - - - - - - - Pages 13-19**

Study this material slowly because every word counts. It isn't exactly essential to understand all this theory in order to fix a receiver having an a.f.c. system or repair an f.m. receiver, but this knowledge will definitely help a lot in most jobs of this type. Furthermore, any man who understands how an a.f.c. system works is really deserving of promotion from the ranks of a beginning student to an advanced group. There are thousands of actual servicemen who do not understand the material you will study here.

☐ **4. Typical A.F.C. Circuits; Adjusting A.F.C. Systems - - - Pages 19-28**

Here are practical examples from actual receivers, to illustrate the theory you learned in the first part of this lesson. Take it slow and easy, because fast reading will get you nowhere in material of this nature. Answer Lesson Questions 7, 8, 9 and 10.

☐ **5. Mail your Answers for this Lesson to N.R.I. for Grading.**

☐ **6. Start Studying the Next Lesson.**

NPC10M948 1948 Edition Printed in U. S. A.

Tuning Indicators and Automatic Frequency Controls for Radio Receivers

Making Receivers Easy To Tune

THE tuning dial of a selective, modern receiver may require adjustments which are accurate to within one-hundredth of an inch movement of the dial pointer on its scale, if the desired signal is to be tuned in properly, free from distortion. The effects of improper tuning upon the wave form of a signal are clearly shown by the diagrams in Fig. *1*.

Receiver designers recognize the difficulties involved in tuning a receiver with this high degree of accuracy, and for this reason have provided a number of tuning aids on the receiver. Large dial scales are provided, with correspondingly longer pointers, to make small movements of the pointer more readily distinguishable. Two-speed adjusting knobs, one turning the tuning condenser assembly directly and the other through a mechanical speed-reducing or vernier mechanism, further simplify accurate tuning.

A dial designed for accurate tuning is of little value if the listener has to rely upon his ears as a guide for proper tuning. The reasons for this are quite simple; loudness is not a dependable guide because about equal loudness is secured for several kilocycles on either side of resonance, due to A.V.C. action. Clarity of reception is likewise a poor guide, for the average individual is not capable of telling immediately whether or not distortion is present. (In a receiver having A.V.C. but no tuning indicator we could, of course, tune for maximum volume with minimum background noise, but few people realize that this can serve as a guide for correct tuning.)

Tuning Indicators. The introduction of automatic volume control practically forced radio designers to develop another improvement, the visual tuning indicator. Fortunately, there is in A.V.C. receivers a voltage or current which either reaches a maximum or minimum value when the receiver is correctly tuned. This voltage or current can be made to operate a simple meter-type indicator having either a needle pointer or a shadow indicator; other types of indicators used for this purpose include a cathode ray indicator tube (often

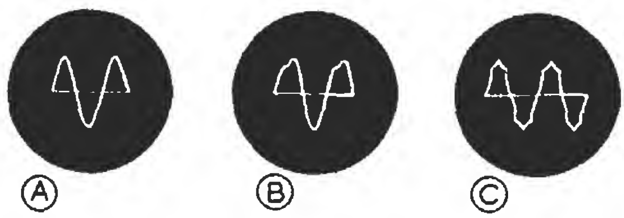


FIG. 1. These diagrams, copied from curves produced on the screen of a cathode ray oscilloscope in the N. R. I. laboratory, show what happens when a selective radio receiver is carelessly tuned. At *A* is the audio output curve secured when the receiver is correctly tuned to a carrier modulated with a single pure sine wave; there is no distortion. The slightly-distorted audio output wave form produced when the receiver is tuned about 2 kc. above the input R.F. carrier frequency appears at *B*, while the severely distorted wave form at 10 kc. off-tune appears at *C*.

called a magic eye), a miniature electric lamp providing flash tuning, or an audio beat oscillator which provides an audible indication of incorrect tuning.

Visual tuning indicators are by no means a perfect solution to this problem of tuning, for even with the best types of indicators the average broadcast listener finds it difficult to tune exactly at all times. Correct tuning requires patience and careful watching of the tuning indicator; a person who is relaxing to enjoy a radio program does not care to bother with the details of proper tuning.

Radio engineers recognize that slight mistuning is relatively unimportant during the first few moments of listening. After the radio receiver has been in operation for an hour or so, however, even small amounts of distortion become objectionable although they cannot consciously be recognized by the listener. Distortion appears to affect the nervous system, making a person tired of listening even to a good program.

Since the success of the entire Radio industry, including broadcasters and receiver manufacturers alike, depends upon having a large listening public, it is only natural that radio receiver engineers continued their search for devices and methods which would simplify the tuning of receivers. Their goal was a system which would permit even a small child to tune in the receiver just as well as could a radio expert.

Automatic Frequency Controls. As you know, in a superheterodyne receiver it is the local oscillator frequency which, more than anything else, determines the value of the I.F. signal. When this I.F. signal frequency is different from the I.F. value of the receiver, due to improper tuning, distortion will be present and sensitivity will be poor.

The superheterodyne receiver circuit is well suited for automatic tuning; even though it may be as much as 5 kc. off resonance, the tuning can be corrected merely by adjusting the oscillator trimmer condenser or by changing the inductance of the oscillator coil.

With this basic superheterodyne principle in mind, radio engineers produced a circuit for developing automatically a voltage which is proportional to the amount by which the oscillator is off resonance. This voltage is fed into a special vacuum tube circuit which is connected to the oscillator and has the peculiar ability of being able to change the inductance or capacity of the oscillator circuit just enough to produce the correct I.F. signal value. This system of automatic frequency control is commonly called A.F.C.

When a receiver is equipped with A.F.C., the listener merely tunes in the desired signal as best he can without any particular attention to accuracy of tuning; the A.F.C. system then automatically completes the tuning procedure.

Automatic frequency control systems are used chiefly in those larger receivers which have some type of automatic push button tuning system; in fact, A.F.C. is essential in a receiver having the electro-mechanical (motor-driven) type of automatic tuning system in order to *correct for slight inaccuracies in the mechanical action of the tuning mechanism and compensate automatically for oscillator frequency drift.*

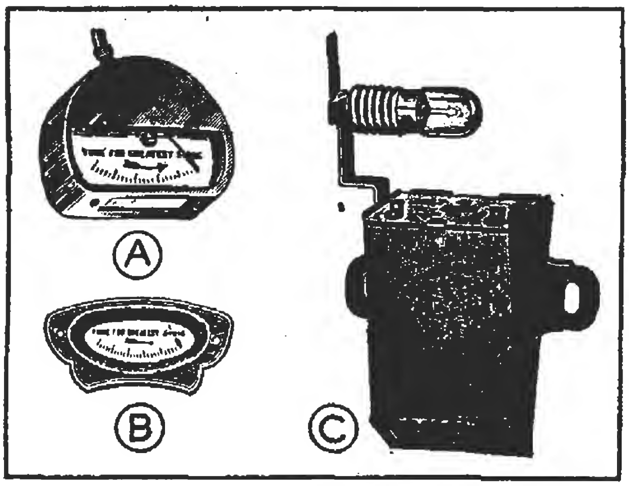


Fig. 2. Examples of current-controlled tuning indicators using an inexpensive milliammeter movement which consists essentially of a solenoid (coil) of about 1000 ohms resistance, inside which moves a long, pointed steel vane to which is attached the indicating pointer. The greater the D.C. current through the solenoid, the greater is the force which pulls the vane into the solenoid and moves the pointer. At C is a shadowgraph tuning indicator using a milliammeter movement; its operating principle is illustrated in Fig. 3.

Tuning aids and automatic frequency control systems provide additional problems for the Radiotrician.

The operating principles of the devices in general use for tuning aids must be thoroughly understood before service can be rendered, so these principles will now be taken up.

Current-Controlled Visual Tuning Indicators

Meter-Type Indicator. Meter-type tuning indicators are ordinarily connected *into the plate supply lead going to one or more A.V.C.-controlled stages.* The average D.C. plate current drawn by a screen grid or pentode tube with normal C bias is about 5 milliamperes; this plate current drops practically to zero when the A.V.C. system increases this negative C bias to 40 or 50 volts. A 0-5 ma. milliammeter movement can therefore be used as a meter-type tuning indicator.

In Fig. *2A* is shown one form of a meter-type tuning indicator. This unit is attached to the receiver chassis in such a way that the face of the meter can be viewed through a hole in the receiver panel. An escutcheon plate like that shown in Fig. *2B* is often used with this meter to improve its appearance, and a pilot lamp is sometimes mounted below the meter to illuminate the scale through the window which can be seen in Fig. *2A*. The no-current position of the pointer is at the extreme right, as shown in these views. With the meter connected to indicate D.C. plate currents of an A.V.C.-controlled stage, the current through the meter is a maximum when no signal is tuned in, and the pointer will be at the extreme left. Tuning in a carrier signal causes A.V.C. action to decrease the D.C. plate current for the A.V.C.-controlled stages, and the tuning meter pointer therefore moves toward its zero position at the extreme right. The listener tunes the receiver for a maximum deflection to the right, or in other words, tunes for greatest swing to the right, for this corresponds to at-resonance conditions in the receiver circuit.

There are a number of variations of the simple meter movement just described, but all depend upon the same operating principles. In one case a small, round black disc is mounted on the end of the meter pointer; this disc moves over a series of concentric circles, alternately black and white, like those on rifle targets. The no-current

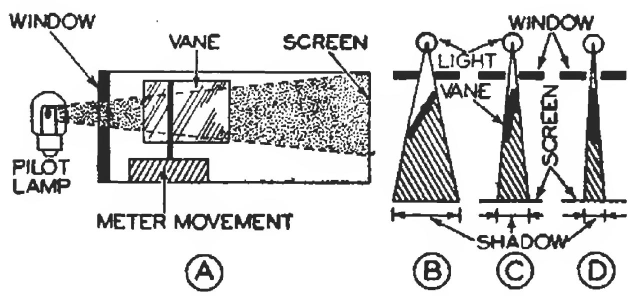


FIG. 3. In this shadowgraph tuning indicator, a large current causes the meter movement to place the vane in position *B*, giving a maximum-width shadow. Tuning in a station reduces the current, making the vane take various positions, such as at *C* and *D*; the listener tunes for minimum shadow, since this corresponds to exact resonance for any station.

position of the disc is at the center of the target, and the listener therefore tunes to get this pointer as close as possible to the center; manufacturers' instructions say: "Tune for a bull's eye."

Shadowgraph Tuning Indicator. Perhaps the most widely used variation of the tuning meter movement is the shadowgraph tuning indicator shown in Fig. *2C*. This contains a frosted glass or celluloid screen which is mounted so as to be visible from the front of the receiver panel. Behind this screen is a pilot lamp, the light from which passes through a small window and past a small rectangular vane attached to the meter movement before reaching the screen. When meter current is a maximum, this vane blocks most of the light, casting a shadow on the screen. As resonance is approached when tuning in a station, the meter movement ro-

tates the vane towards its zero position, giving a minimum-width shadow. Details of this arrangement are shown in Fig. *3A*, and the effects of vane position upon the width of the shadow are shown in Figs. *3B*, *3C* and *3D*.

Circuit Connections. When a tuning meter is to be actuated by the D.C. plate current of only one A.V.C.-controlled stage, connections into the plate supply lead of this A.V.C.-controlled tube may be made as shown

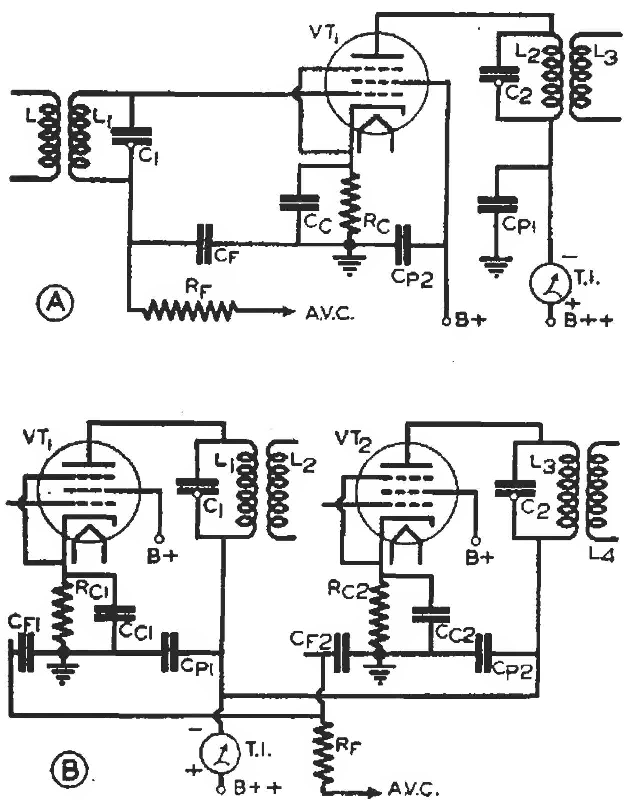


FIG. 4. Connections for a meter-type tuning indicator for a single A.V.C.-controlled stage *(A)* and for the common plate supply lead to two A.V.C.-controlled stages *(B)*.

in Fig. *4A*. Notice that by-pass condenser C_{P1} prevents R.F. and I.F. currents from passing through the tuning indicator. The resistance of the tuning indicator drops the D.C. plate voltage about 5 to 10 volts.

When the D.C. plate current to more than one A.V.C.-controlled amplifier stage is passed through the tuning indicator, connections into the plate supply lead going to these A.V.C.-controlled tubes may be as shown in Fig. *4B*. Naturally the current range for the indicator in this circuit must be greater than for the tuning indicator in Fig. *4A*. The meter movement should be selected to give nearly full-scale deflection to the left for a no-carrier-signal condition, in order to give maximum meter movement when a station is tuned in. Notice that by-pass condensers C_{P1} and C_{P2} are used in this arrangement to keep R.F. and I.F. currents out of the tuning indicator.

Voltage-Controlled Visual Tuning Indicators

Cathode Ray Tuning Indicator. A special cathode ray tube which acts essentially as a high-resistance voltmeter is used in many receivers as a voltage-controlled visual tuning indicator. The *D.C. voltage developed across the load resistor of a diode second detector-A.V.C. tube* in a receiver is used to control the cathode ray tuning indicator, since this voltage varies with carrier level.

The operating principle of a cathode ray tuning indicator tube is essentially the same as that of the cathode ray oscilloscope tube. Electrons striking a surface coated with a fluorescent material (such as willemite) cause the surface to glow with a greenish light. The diode detector load voltage determines the amount of surface which glows at any time, and thus we have a simple and highly attractive tuning indicator.

In a cathode ray tuning indicator an oxide-coated cathode, heated by a filament, is mounted in the center of a cone-shaped anode having a coating of fluorescent material on its inner surface, as indicated in Fig. *5A*. When a D.C. voltage is applied between the cathode and the anode, the electrons emitted by the heated cathode will strike the inner surface of the anode, called the *target,* and the entire inside of the circular cone or tar-

get will glow with a greenish light. In addition, a thin, vertical dart or vane is located between the target and the cathode, as shown in Fig. *5B*. This dart is known as the *control*

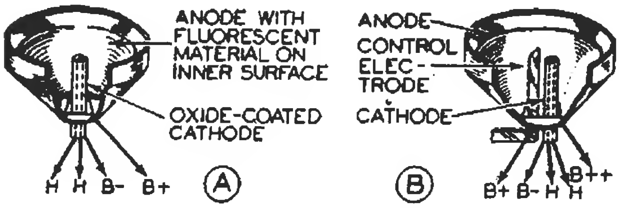


FIG. 5. Essential elements of a cathode ray tuning indicator tube.

electrode, for it determines how much of the target will glow.

When the control electrode is connected to the cathode, it has no electrical influence upon the electrons emitted by the cathode, but does have a physical blocking effect which prevents electrons from reaching that portion of the target directly behind it. We thus have a shadow in back of the control electrode, as indicated in Fig. *6A*. Making the control electrode negative with respect to the cathode, as in Fig. *6B,* widens this shadow, for the control electrode now has a repelling effect on the emitted electrons. When the control electrode is made positive with respect to the cathode, however, it serves to speed up the emitted electrons and to make them bend towards the shadow region, narrowing the shadow as indicated in

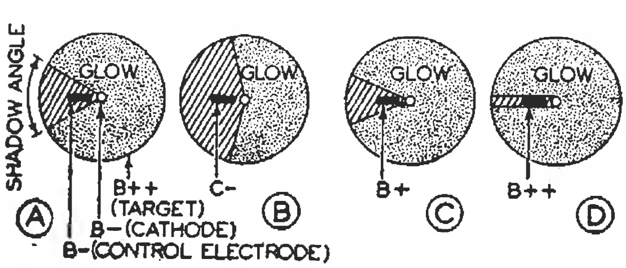
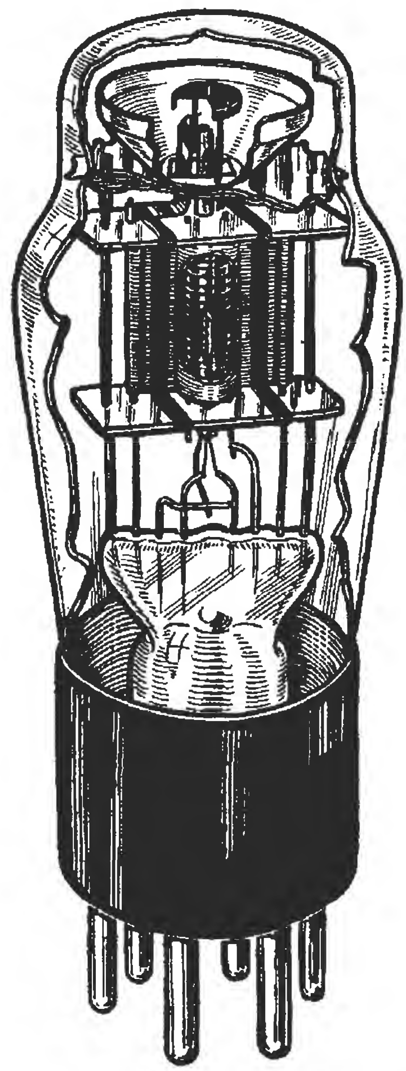


FIG. 6. Variation of shadow angle with control electrode potential in a typical cathode ray tuning indicator tube.

Fig. *6C*. When the control electrode is highly positive, as in Fig. *6D,* the shadow becomes very narrow or disappears entirely.

When a receiver having a diode detector is tuned to resonance, the diode load voltage increases in a negative direction with respect to the chassis or ground. If we want the shadow angle to close up as a station is tuned in, we must convert this increasing negative voltage into an increasing positive voltage for the control electrode of the cathode ray indicator



Courtesy National Union Radio Corp.

FIG. 7. Cutaway view showing construction of 6G5 cathode ray tuning indicator tube.

tube. This can quite easily be done by introducing a triode amplifier between the detector load and the control electrode of the indicator tube; in an actual cathode ray indicator tube like that shown in Fig. *7*, this triode amplifier is built into the same envelope as the target system.

The schematic circuit diagram in Fig. *8* gives in simplified form exactly the same information as the pictorial sketch in Fig. *7*. In addition, this

diagram shows that the target connects directly to the B++ D.C. supply source, while the plate of the triode tube connects to this source through resistor R, which is usually 1 megohm. The common cathode for the two tubes is grounded to the receiver chassis, and the A.V.C. voltage is applied between the control grid of the triode section and the cathode.

When a receiver which has a cathode ray tuning indicator is tuned be-

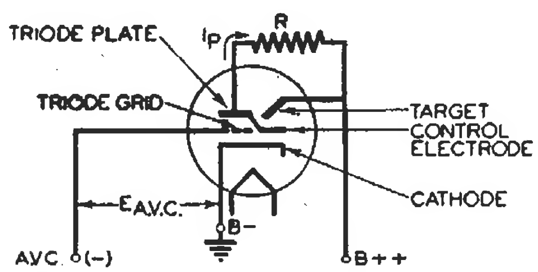


FIG. 8. Schematic symbol for a cathode ray tuning indicator tube. External resistor R is always used between the triode plate and the target. Circuit variations have little effect upon target current, since the target receives a constant D.C. supply voltage.

tween stations, there is no carrier signal and consequently there is no A.V.C. voltage developed across the detector load resistor. Under this condition the C bias for the triode section of the indicator tube is zero (E_{AVC} is zero) and D.C. plate current I_P for the triode section depends upon the B++ supply voltage, the value of resistor R and upon the plate-to-cathode resistance of the triode section. Since this plate-to-cathode resistance is quite low for zero grid bias, current I_P is high, and creates a high voltage drop across R. The triode plate voltage is consequently considerably less than the target voltage (because of this drop across R). The control electrode (connected directly to the triode plate) likewise has considerably less voltage than the target when no station is tuned in, and the shadow angle is therefore large.

When the receiver is tuned to a desired station carrier signal (is tuned to resonance), the A.V.C. voltage developed across the detector load increases, driving the triode grid of the indicator tube negative and increasing the D.C. plate resistance of the triode section. The result is reduced D.C. plate current and a lowered voltage drop across resistor R. The triode plate voltage and the control electrode voltage become more nearly equal to the target voltage, and the increasing positive voltage on the control electrode decreases the shadow angle on the target. This shadow angle will be a minimum when the receiver is tuned exactly to resonance for a particular station. For distant stations the minimum shadow angle will be considerably greater than for local stations.

It is possible to adjust a cathode ray indicator tube circuit to make the shadow vanish for either small or large A.V.C. voltages. With circuits designed so the shadow closes on low A.V.C. voltages, however, the tuning in of strong carrier signals will completely close the shadow before resonance occurs and an exact indication of resonance will not be possible. On the other hand, if the circuit is designed so the shadow will completely close only for strong local carrier signals, then the change in shadow angle for weak signals may be inadequate for accurate tuning. (This is not a serious drawback, however, for it is ordinarily easy to tune in a *weak* station accurately by ear.)

The A.V.C. voltage is, of course, the primary control upon the shadow angle. The angle for zero A.V.C. voltage is governed essentially by the design of the tube, but the amount which the shadow closes for a given increase in A.V.C. voltage is determined by the target voltage and by the value of series resistor R.

Curve *1* in Fig. *9* tells how the shadow angle varies with A.V.C. voltage when the supply voltage is low

(100 volts) and the ohmic value of *R* is low (.5 megohm). Observe that the shadow angle is 90 degrees for zero A.V.C. voltage, and the shadow is completely closed (0° shadow an-

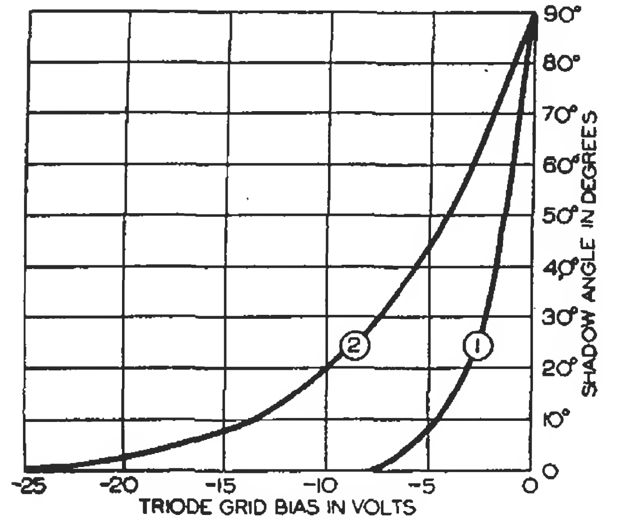


FIG. 9. This graph shows how shadow angle varies with grid voltage for a 6G5 cathode ray tuning indicator tube. Curve 1: R = .5 megohm and B++ voltage = 100 volts; curve 2: R = 1 megohm and B++ voltage = 250 volts.

gle) at an A.V.C. voltage of about —8 volts (the curves in Fig. *9* apply to a 6G5 tube). Curve *2* in Fig. *9* is for a high plate supply voltage and a high value of *R;* in this case the shadow does not close until the A.V.C. voltage has driven the triode tube grid to —23 volts.

We can draw the following conclusions from the curves in Fig. *9: 1,* to make the shadow close at a more negative grid bias value, increase the supply voltage to the tube; *2,* to make the shadow close at a less negative value (so it will close for weak carrier signals), reduce the supply voltage to the tube. To secure the desired open shadow angle, usually about 90 degrees, adjust resistor *R* when no carrier signal is present. With these facts in mind, you will be able to adjust a cathode ray indicator tube for satisfactory operation on either local or distant stations. Most receivers are adjusted for a characteristic curve approximating curve *2* in Fig. *9,* for this gives a reasonable change in shadow angle at all reasonable carrier levels.

Adding a Cathode Ray Indicator Tube to a Receiver. A suitable circuit is shown in Fig. *10A;* all parts which are added to the original receiver circuit are shown in heavy lines. Note that the grid of the 6G5 cathode ray tuning indicator tube is connected through a 1-megohm resistor R_1 to the A.V.C. voltage source in the receiver. This connection could be to the minus terminal of the diode detector load, but since this terminal may furnish as much as —40 volts when a strong local station is tuned in, it is better to place voltage divider R_2-R_3 across the diode load and make a connection to this.

The larger the value of R_2 with respect to that of R_3, the lower will be the maximum A.V.C. voltage applied to the indicator tube. R_1 prevents the 6G5 tube from shorting the diode load

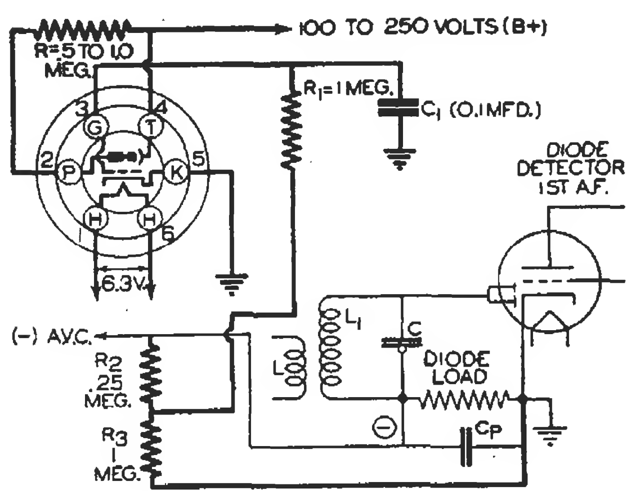


FIG. 10A. This diagram shows you how a cathode ray indicator tube would be connected between the A.V.C. supply terminal and ground in a receiver. The only extra parts required, in addition to the type 6G5 indicator tube and its standard 6-prong socket, are resistors *R*, R_1, R_2 and R_3, and condenser C_1. You will sometimes find the control electrode and target represented as shown here rather than as in *Fig. 8*, so learn to recognize both types of diagrams.

or the voltage divider; in addition, R_1 serves with C_1 as an A.F. filter which prevents the shadow from flickering at an A.F. value.

Wide-Angle Tuning. The shadow angle for a no-signal condition in the

average cathode ray tuning indicator tube is 90°, but this can be increased approximately to 180° by inserting an ordinary triode amplifier tube between the A.V.C. supply terminal and the indicator tube in the manner shown in Fig. *10B*.

When there is no carrier signal in the diode second detector circuit of a receiver, there is no A.V.C. voltage developed across the diode load, and consequently the grid of VT_1 in Fig. *10B* will be at zero bias. The plate

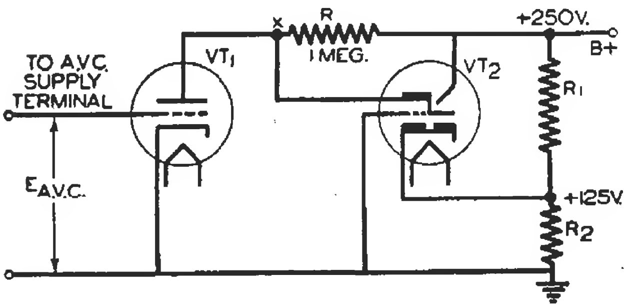


FIG. 10B. A shadow angle of approximately 180° can be secured with this cathode ray tuning indicator circuit.

current of this tube is then high, and the plate-cathode resistance of VT_1 drops so low that point x is nearly at ground potential. Since the cathode of VT_2 is +125 volts with respect to ground, the triode plate and the control electrode of VT_2 are —125 volts with respect to the cathode of this tube; under this condition the shadow angle is approximately 180°.

When a highly negative A.V.C. voltage is applied to the grid of VT_1 (tuning the receiver to a powerful local station would do this), the plate current of VT_1 drops nearly to zero; under this condition the D.C. resistance of VT_1 is so much higher than the 1-megohm resistance of R that point x practically assumes B+ potential of +250 volts. This places the triode plate and the control electrode at about +125 volts with respect to the cathode of VT_2, giving zero shadow angle. Weaker signals give shadow angles between 0 and 180°, with the change in shadow angle while tuning in a station being about twice as great as for an ordinary indicator circuit; this, of course, makes more accurate tuning possible.

Unique Tuning Aids

Although the milliammeter and the cathode ray tuning indicator tube are the most widely used tuning aids, a number of other unique methods have been developed. Three of these will be considered at this time: *1*, the G.E. Colorama indicator, using red and green lamps; *2*, the neon lamp flasher; *3*, the zero beat tuning indicator.

G. E. Colorama Tuning Indicator. The circuit diagram of the Colorama tuning indicator used in a number of General Electric receivers is shown in Fig. *11*. The A.V.C. voltage developed by the diode detector in the receiver is applied to the control grid of an ordinary type 6C5 triode tube (designated as the Colorama tuning indicator tube). In the plate circuit of this tube is the primary of the Colorama tuning reactor (an iron-core transformer) while across the secondary of this transformer is an arrangement of three green lamps in series and four red lamps in series-parallel, connected as indicated in Fig. *11*. Condenser *C52*, across the primary of the transformer, serves to filter out any A.F. components in the A.V.C. voltage; *R28* and *C53* are power pack supply filters.

When the A.V.C. voltage is low or zero, as it is when the receiver is tuned off resonance or between stations, the C bias on the 6C5 tube is zero and D.C. plate current for this tube is therefore quite high. This high plate current flowing through the primary of the Colorama tuning reactor saturates its iron core. *This core saturation lowers the reactance of the secondary winding*, so that it is

practically a short-circuit path for 60-cycle alternating current. Under this condition the green lamps are in effect shunted by the 15-ohm resistor *R30*, and the current which is sent through the bank of red lamps and *R30* by secondary winding *S* on the receiver power transformer is high enough to light all of the red lamps. We thus have the red lamps glowing whenever the A.V.C. voltage is reduced by tuning between stations.

Now let us see what happens when a station is tuned in. Tuning the receiver to resonance increases the negative A.V.C. voltage applied to the grid of the 6C5 tube, and the plate current of this tube drops. The core of the Colorama tuning reactor becomes less saturated as primary current drops, and consequently the inductance of secondary winding *L28* increases. The reactance of this secondary winding at 60 cycles is correspondingly increased, reducing the shunting effect of *R30* and thus increasing the resistance of the entire circuit across transformer winding *S*. Less current now flows through the red lamps, and they begin to grow dim.

At a critical negative A.V.C. voltage, full current (.150 ampere in this case) flows through the green lamps, lighting them brightly, while the current through a red lamp is only half of the circuit current, because of the series-parallel connection. Resistor *R30* controls the maximum current which can flow through the red lamps when the receiver is off-tune, while resistor *R29* controls the current which the green lamps can draw when the receiver is tuned to a station, and also controls to a certain extent the current for the red lamps. These resistors must be properly adjusted if the red lights are to illuminate the station selector dial when the receiver is off resonance, and the green lights are to illuminate the dial when the receiver is at resonance.

Neon Lamp Flasher Indicator. A single neon lamp connected into a circuit which causes it to glow only when a station is tuned in, serves as the tuning indicator for a number of Silvertone receivers. The circuit diagram is shown in Fig. *12;* an ordinary I.F. transformer with weak coupling

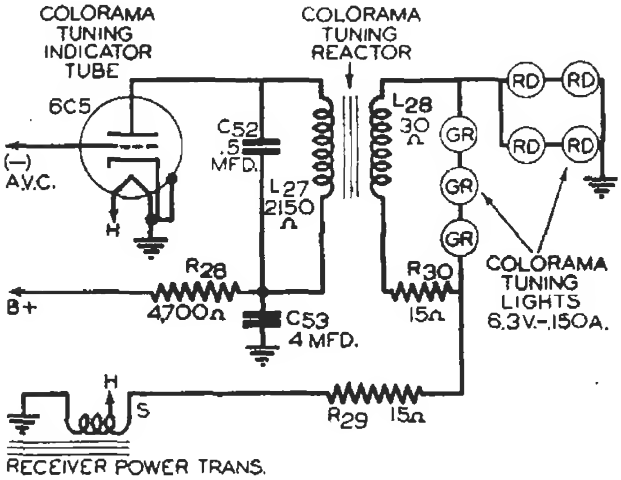


FIG. 11. Circuit diagram of the Colorama tuning indicator used in General Electric Models E-101, E-105 and E-106 receivers. The green lamps light up when the receiver is properly tuned; red lamps *illuminate tuning dial whenever receiver is off tune.* The reactance values given here for the primary and secondary (*L27* and *L28*) of the Colorama tuning reactor are for 60 cycles A.C. Ohmmeter measurements will therefore give considerably lower values.

between the tuned primary and tuned secondary is connected between the primary of the last I.F. transformer and the 6B7 duo-diode-pentode which is designated as the flasher tube. Primary circuit L_1-C_1 of this extra I.F. transformer forms a series resonant circuit which is connected across condenser *C* in the last I.F. transformer circuit, with the result that the small I.F. voltage drop across condenser *C* is applied to L_1-C_1. At resonance this series resonant circuit acts as a low resistance, and hence does not affect the plate load of the last I.F. stage. Loose coupling between L_1 and L_2 insures higher selectivity for resonant circuits L_1-C_1 and L_2-C_2 than could be secured in the I.F. amplifier, for

we are not concerned with fidelity in the tuning indicator circuit.

The I.F. voltage developed across resonant circuit L_2-C_2 is rectified by the diode section of the 6B7 flasher tube, and a rectified voltage is developed across the 1-megohm diode load resistor. The control grid of the pentode section is connected to the negative terminal of this load resistor.

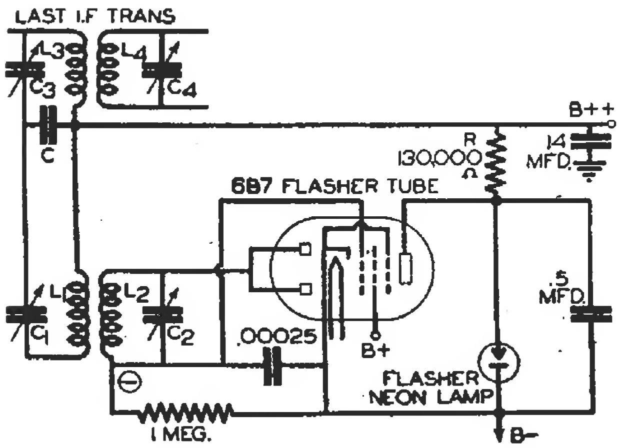


FIG. 12. Neon lamp flasher indicator circuit as used in Silvertone Models 1722 and 1732 receivers. The neon flasher lamp glows only when the receiver is tuned correctly.

The plate of the pentode section receives its D.C. voltage through 130,000-ohm resistor *R*; between the plate and the cathode is the flasher neon lamp which glows only when its terminal voltage exceeds a definite value. Furthermore, the terminal voltage of this neon lamp is equal to the supply voltage minus the voltage drop in resistor *R*.

When the receiver is tuned off resonance, little or no I.F. voltage is applied to the diode section of the 6B7 flasher tube. As a result, no rectified voltage exists across the 1-megohm resistor, the C bias on the pentode section is practically zero, and plate current of the pentode section is high. This plate current produces a large voltage drop across resistor *R*, making the neon lamp voltage too low for it to glow. Since resonant circuits L_1-C_1 and L_2-C_2 are highly selective, the receiver must be tuned exactly to resonance before enough I.F. signal can get through these circuits to excite the diode section and produce sufficient negative voltage across the 1-megohn resistor to reduce the pentode plate current to a low value. Reducing the plate current reduces the voltage drop across *R* and raises the neon lamp voltage. The lamp therefore glows when the receiver is properly tuned to a station. When the receiver is tuned rapidly from station to station, the lamp flickers each time a station is passed; this is why this particular arrangement is known as a flasher indicator.

Zero Beat Tuning Indicator. If the I.F. carrier signal produced by the mixer-first detector of a receiver is mixed with a locally-produced signal having exactly the correct I.F. value, and this mixing occurs just ahead of the second detector, an audio beat (low-frequency audio note) will be heard in the loudspeaker whenever the receiver is improperly tuned to a station.

When the receiver is properly tuned, the difference between the two I.F. signals will be less than 30 cycles, and the beat note will therefore be inaudible. When the receiver is tuned off a station, there will be no incoming I.F. signal to beat with the locally produced signal, and consequently no audio beat will be heard. A zero beat indicator of this type is entirely satisfactory provided the listener does not object to the squeal which occurs while tuning in a station. Furthermore, this indicator is effective regardless of whether the I.F. amplifier is peaked or band-passed. A zero beat tuning indicator is also of great value when tuning in continuous wave code signals, for it provides an audible tone for these signals.

The special local oscillator circuit which is used as a zero beat tuning indicator in one receiver is shown in

Fig. 13. The oscillator tank circuit is made up of L_1 and C_1, with C_1 being adjusted to make this circuit produce a frequency exactly equal to the I.F. value of the receiver. A.C. plate

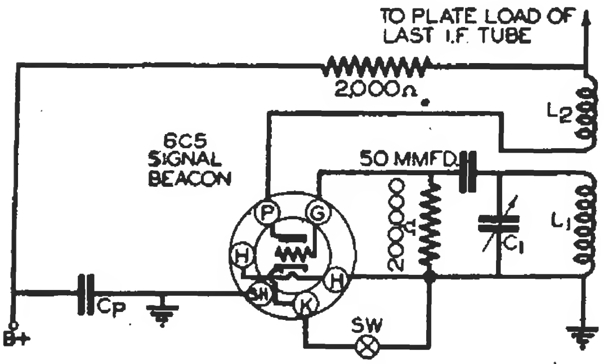


FIG. 13. Circuit of the R.F. oscillator which serves as a zero beat tuning indicator in the Grunow Model 12A-1241 receiver.

current flowing through coil L_2 induces in L_1 the feed-back voltage required for oscillation. The A.C. plate current produced by this oscillator flows through a 2,000-ohm resistor which is also in the plate supply lead of the last I.F. amplifier stage. The result is that an A.C. voltage is superimposed on the D.C. plate voltage applied to this last I.F. stage. Two signals, the exact I.F. signal produced by the oscillator and the I.F. signal produced by tuning the receiver to a station, reach the second detector. After detection, we have left the desired audio signal and a beat note equal to the difference between the two I.F. signals; when the receiver is accurately tuned to a station, this difference will be zero, the beat note will disappear, and we have what is known as zero beat.

Essential Sections of an A.F.C. System

The two essential sections of an A.F.C. system are: *1, the discriminator,* which usually produces a positive D.C. control voltage for below-normal I.F. signal frequencies, and a negative D.C. control voltage for above-normal I.F. signal frequencies with the value of this voltage being proportional to the amount of error in tuning; *2, the oscillator control circuit,* which converts the *D.C. control voltages* (produced by the discriminator) into changes in the effective inductance shunting the oscillator coil, thereby compensating for errors in tuning. The positions of these sections with respect to the other stages of a conventional superheterodyne receiver having A.F.C. are clearly shown by the box diagram in Fig. *14*. Note that the I.F. amplifier feeds both the discriminator and the second detector.

The Discriminator Circuit

Typical Discriminator Circuit. The easiest way to see how the discriminator circuit in an A.F.C. system can furnish a D.C. control voltage of suitable polarity is to consider an actual discriminator circuit, as given in Fig. *15* We will first "get our bearings" by analyzing this circuit in a general manner, after which we will be ready to consider in detail the manner in which the D.C. control voltage is produced.

In the input circuit for the discriminator tube in Fig. *15* we find parallel resonant circuit L_P-C_P serving as the plate load for the last I.F. stage, and inductively coupled to series resonant

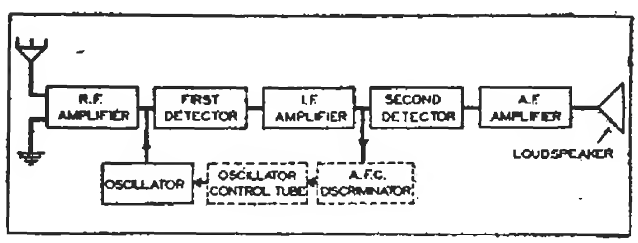


FIG. 14. The two sections shown in dotted lines must be added to a superheterodyne receiver in order to secure automatic frequency control.

circuit L_1-L_2-C. Both of these resonant circuits are tuned to the exact I.F. value of the receiver. The coil in the series resonant circuit is split into two section of equal size L_1 and L_2, and

the plate (high R.F.) terminal of the parallel resonant circuit is connected to the common terminal of these coils through D.C. blocking condenser C_B.

The discriminator tube is a double diode rectifier tube (a 6H6 tube is most generally used), with the plate of each diode section connected to one terminal of the series resonant circuit and the cathodes connected together through equal-value resistors R_1 and R_2. Each resistor is shunted by a by-pass condenser (C_1 and C_2) and one cathode is grounded directly, hence both cathodes of the discriminator tube are at ground I.F. potential.

Notice now that the I.F. voltage developed across the parallel resonant circuit in the last I.F. stage is applied across choke coil *CH*, this I.F. voltage being designated as e_P (condenser C_B provides a direct path for I.F. current from the plate end of the parallel resonant circuit to point *1* and one terminal of the choke coil, and the path from the other end of the parallel resonant circuit is through by-pass condenser C_3 to the receiver chassis, through the chassis to the grounded end of R_2 and then through by-pass condenser C_2 to point *2* and the other terminal of the choke coil). This I.F. voltage e_P developed across choke coil *CH* is in turn applied to points *1* and *2* in the discriminator circuit.

Current *i*, flowing through the coil of the parallel resonant circuit, induces into secondary coil L_1-L_2 a voltage which we will designate as e_S. This voltage acts in series with L_1, L_2 and C in our series resonant circuit, causing a current to flow through the two coil sections. This current develops I.F. voltage e_1 across coil section L_1 and develops I.F. voltage e_2 across coil section L_2. For any condition of tuning, voltage e_1 will always be equal to e_2 *in magnitude.*

We can now see that I.F. voltage e_1 acts in series with I.F. voltage e_P on diode section D_1, and the resulting rectified electron current i_1 flows through R_1, developing across this resistor a D.C. voltage having the polarity indicated in Fig. *15*. Likewise, e_2 and e_P act upon diode section D_2, and rectified electron current i_2 produces a D.C. voltage across R_2 with the polarity shown.

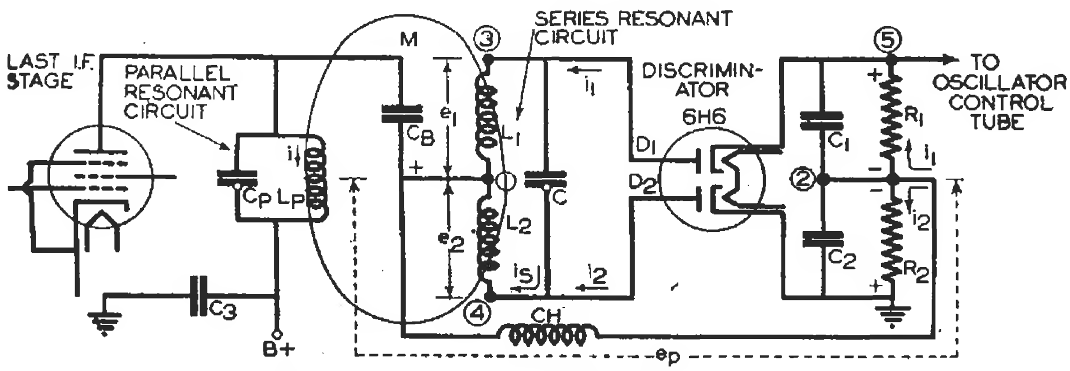


FIG. 15. Conventional discriminator circuit.

Since we are dealing with A.C. voltages in this discriminator circuit, phase must of course be taken into account when we consider their combined effects.

Correct Tuning. When the phase difference between e_1 and e_P is the same as that between e_2 and e_P, the net voltages acting upon diode sections D_1 and D_2 will be equal in magnitude; equal values of rectified current will then flow through the two resistors, making the D.C. voltage drop across R_1 equal to that across R_2. The net D.C. control voltage produced across these two resistors (between point *5* and ground) will be

opposite polarity, and the A.F.C. system will have no effect upon the oscillator. This is, of course, the condition for correct tuning of the receiver to a station.

Incorrect Tuning. When the frequency of the received I.F. signal does not correspond to the resonant frequency of the tuned circuits in the

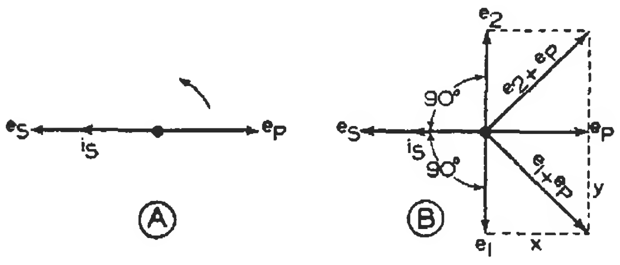


FIG. 16. Vector diagrams showing conditions in the discriminator circuit when the receiver is correctly tuned.

discriminator (because of incorrect tuning), e_1 and e_2 no longer have the same phase relationship with e_P, and consequently the A.C. voltages acting upon the diode sections are different in magnitude. Unequal rectified currents through R_1 and R_2 produce unequal voltage drops which, when combined, leave the desired D.C. control voltage to act upon the oscillator control circuit and correct for the error in tuning.

Since any detailed analysis of the action of an A.F.C. system must necessarily involve phase, it will be well at this time to review the fundamental facts about phase which you have already studied.

Review of Phase

All the information you need know about the phase relationships of voltages and currents for the parts in an A.F.C. circuit is given in Chart *1*, page 27. The essential facts presented by this chart, particularly by the vector diagrams in the fourth column, are:

Resistors: The voltage across a resistor is *in phase* with the current through it.

the current through it by 90° (the current therefore *lags* the voltage by 90°).

Condensers: The voltage across a perfect condenser *lags* the current through it by 90° (the current therefore *leads* the voltage by 90°).

Transformers: The voltage *induced* in the secondary winding of a transformer (the open-circuit secondary voltage) is 180° out of phase with the primary voltage.

Discriminator Circuit Action

When the I.F. Signal Frequency is Correct. We will first analyze the discriminator circuit in Fig. *15* for the condition where the input I.F. signal frequency exactly corresponds to the I.F. value of the receiver. In this case parallel resonant circuit C_P-L_P and series resonant circuit L_1-L_2-C will be resonant to the incoming signal. To determine the net A.C. voltages acting on diode section D_1, we must add together A.C. voltages e_P and e_1 vectorially, so as to take into account the phase relationship of these two voltages. Likewise we must add together e_2 and e_P vectorially to find the net A.C. voltage acting upon diode section D_2. First of all, we must choose some voltage or current for reference purposes; since e_P is common to all circuits under study, we shall use it as our reference voltage. To fix this fact in mind, we draw our vector e_P along the reference line in our vector diagram, as in Fig. *16A*, using any convenient scale to determine its length.

The voltage e_S which is induced in the secondary of the discriminator transformer is 180° out of phase with the voltage across the primary (see diagram *P* in Chart *1*), and consequently we can say that e_S is 180° out of phase with e_P. We therefore place vector e_S on our vector diagram

in the opposite direction from e_P, as indicated in Fig. *16A*.

Since the frequency of induced secondary voltage e_S is exactly the same as the resonant frequency of series resonant circuit L_1-L_2-C, this circuit acts like a resistance at resonance and e_S will send through the circuit a current i_S which is *in phase* with e_S, as shown in Fig. *16A*. Current i_S flows through L_1 and L_2, developing across each of these coil sections an A.C. voltage which leads the current by 90° (see diagram *H* in Chart *1*).

Rather than confuse the diagram in Fig. *16A* by adding more vectors to it, let us redraw it in Fig. *16B* and place vectors e_1 and e_2 on this new diagram. Before these vectors can be drawn, however, one other factor must be taken into account. For any direction of current flow i_S through L_1 and L_2, one of the coil voltage drops will be opposite in polarity (180° out of phase) with the other coil voltage drop in so far as e_P is concerned. This is because e_P acts in opposite directions through the two coils (it acts in the direction from point *1* to point *3* through L_1 and from point *1* to point *4* through L_2). For this reason, if we show voltage drop e_1 as leading i_S by 90°, we must show e_2 as lagging i_S by 90°, making e_1 180° out of phase with e_2. (We could just as well make e_2 lead i_S by 90° and make e_1 lag i_S by 90°, for the same results would be secured.) Now we can draw in vector e_1 and e_2, as shown in Fig. *16B*.

The next step is to find the net A.C. voltage acting upon diode section D_1 through resistor R_1. As was said before, this voltage will be equal to $e_P + e_1$ with phase taken into account. We can add these two voltages quite easily on the vector diagram in Fig. *16B*; we simply complete the parallelogram (rectangle) of which e_1 and e_P form two sides, as indicated by the dotted lines *x* and *y* in Fig. 16B, and then draw a line from the center of our vector diagram to the intersection of these dotted lines. This line now represents the vectorial sum of voltages e_P and e_1, so we label this vector in this way. The length of vector $e_1 + e_P$ corresponds to the magnitude of the A.C. voltage acting upon diode section D_1. In a similar manner we determine that vector $e_2 + e_P$ is the net A.C. voltage acting upon diode section D_2.

These net A.C. voltages acting upon the diode sections will always be exactly equal when the I.F. signal frequency corresponds exactly to the I.F. value of the receiver. The diode sections D_1 and D_2 will consequently pass currents of equal value, and the D.C. voltage developed across R_1 by diode current i_1 will exactly equal the D.C. voltage developed across R_2 by diode current i_2. Note that these currents flow in opposite directions through R_1 and R_2, making the voltage drops across these resistors have the polarities indicated. The net D.C. voltage developed across the two resistors (between point *5* and ground) for the oscillator control circuit is therefore zero whenever the I.F. signal is of the exact value.

When the I.F. Signal Frequency is High. When the I.F. signal frequency entering the discriminator circuit is higher than the I.F. value of the receiver (higher than the resonant frequencies of L_P-C_P and L_1-L_2-C), we will naturally expect the discriminator circuit to produce a D.C. control voltage for the oscillator control circuit. Let us see how this is done.

Primary voltage e_P will again be used as our reference voltage for the vector diagram. The induced voltage e_S will again be 180° out of phase with the primary voltage e_P, so we draw the vectors for these two values as in Fig. *17A*.

Since the frequency of e_S is higher

than the resonant frequency of series resonant circuit L_1-L_2-C, the reactance of coils L_1-L_2 will be greater than the reactance of condenser C, and the entire series resonant circuit will act as an inductance whose reactance is equal to the difference between the above-mentioned reactances. We thus have voltage e_s acting upon a coil; if there were no resistance in this circuit, we could say that circuit current i_s lags the applied voltage by 90° (Chart *1*). Since this series resonant circuit has a certain amount of A.C. resistance, however, and since the net inductance is quite low near resonance, the current i_s will lag the voltage e_s by less than 90°. For explanation purposes, let us assume that series resonant circuit current i_s lags e_s by 45°. We therefore draw vector i_s lagging behind e_s by 45°, as indicated in Fig. *17A*.

Regardless of the phase relation between i_s and e_s, the voltage drops across coil sections L_1 and L_2 will lead current i_s by 90°, and since one voltage drop acts in the opposite direction from the other in so far as e_P is concerned, we can say that A.C. voltage e_1 leads circuit current i_s by 90°, and A.C. voltage e_2 lags i_s 90°. We will leave Fig. *17A* as it is, and redraw the vectors in Fig. *17B* for the complete vector diagram. Vectors e_1 and e_2 are now placed on this diagram.

Again we add e_1 and e_P, taking phase into account, to find the net A.C. voltage acting upon diode section D_1. We do this by drawing lines x and y in Fig. *17B* to complete the parallelogram having e_1 and e_P for for two of its sides. The diagonal line drawn from the center of the vector diagram to the intersection of these dotted lines now represents the net A.C. voltage, $e_1 + e_P$, acting upon diode section D_1.

In the same manner we add A.C. voltages e_2 and e_P in Fig. *17B*, getting the somewhat longer vector $e_2 + e_P$ as the net A.C. voltage acting upon diode section D_2. We can see immediately that vector $e_2 + e_P$ is longer than vector $e_1 + e_P$; this means that a higher voltage acts upon diode section D_2 than upon D_1 in Fig. *15*, and a higher rectified current therefore flows through R_2 than through R_1. The D.C. voltage drop across R_2 will therefore be greater

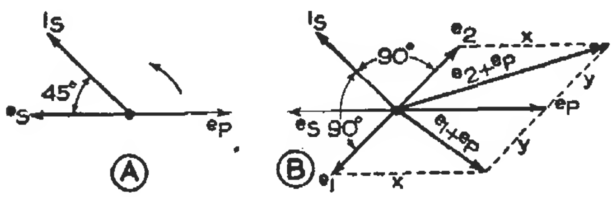


FIG. 17. Vector diagrams showing conditions in the discriminator circuit when the I.F. signal frequency is higher than the I.F. value of the receiver.

than the D.C. voltage drop across R_1, and only a part of the drop across R_2 will be canceled out by the drop across R_1. This leaves point *5* negative with respect to ground and this negative D.C. voltage constitutes the D.C. control voltage applied to the oscillator control circuit. The higher the I.F. signal is above the I.F. value of the receiver, up to a certain limit, the higher will be this negative D.C. control voltage.

When the I.F. Signal Frequency is Low. If we repeat our analysis of the discriminator circuit in Fig. *15* and draw a vector diagram for the condition where the I.F. signal frequency is lower than the I.F. value of the receiver, we would find that net A.C. voltage $e_1 + e_P$ would be larger than $e_2 + e_P$, with the result that diode section D_1 produces a higher rectified voltage across R_1 than diode D_2 does across R_2. The drop across R_2 would cancel out only a part of the drop across R_1, with the result that the D.C. control voltage between point *5* and ground would have the same polarity as the drop across R_1. The

net D.C. control voltage is therefore *positive* with respect to the ground or chassis when the I.F. signal frequency is *lower* than the I.F. value of the receiver.

S Curve for Discriminator Circuit. The manner in which the D.C. control voltage produced by the discrimi-

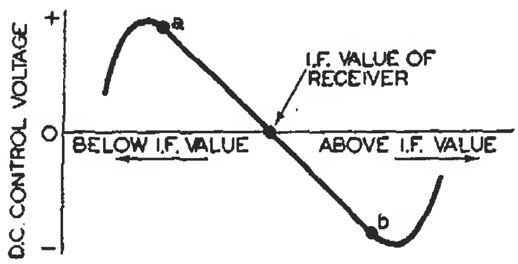


FIG. 18. S-curve showing output characteristics of a discriminator circuit.

nator varies with the I.F. signal frequency is usually expressed by radio engineers in the form of a graph like that in Fig. *18*. The curve on this graph is called an *S curve*. Note that a positive D.C. control voltage is produced for I.F. signal frequencies below the I.F. value of the receiver, and a negative D.C. control voltage is produced for I.F. signal frequencies above the I.F. value; this verifies the results of our analysis of the circuit in Fig. *15*. Observe also that the D.C. control voltage increases quite uniformly as we go above or below resonance, up to points *a* and *b*. The part of the curve between these two points is the operating range for the discriminator; slightly beyond *a* and *b*, further deviations from the resonant frequency do not give additional increases in D.C. control voltage. As a result, there is insufficient control beyond these points and A.F.C. action is not complete. From a practical standpoint, this means that I.F. signal frequencies between points *a* and *b* will be properly corrected by the A.F.C. system, while frequencies outside this range will not be "pulled in" satisfactorily.

The Oscillator Control Circuit

The D.C. control voltage developed by the discriminator (sometimes called the *discriminator voltage*) must be converted by the oscillator control circuit into an action which will increase or decrease the oscillator frequency the correct amount to make the I.F. signal frequency exactly equal to the I.F. value of the receiver. Since the frequency developed by the oscillator circuit is essentially controlled by the capacity of the oscillator tank circuit condenser and the inductance of the tank coil, this D.C. control voltage must be converted into a capacity or inductance which, when applied to the oscillator resonant circuit, will give the necessary change in frequency. In a practical oscillator control circuit, the vacuum tube is usually made to act as an inductance, for this produces a more uniform A.F.C. action over the entire band.

Before taking up an actual oscillator control circuit, let us see how we can tell when a vacuum tube is acting as a coil. We know that when a coil is connected to an A.C. voltage source, the current drawn by the coil will lag the voltage by 90°. Suppose we had a box with two terminals, and some unknown electrical device inside. If we connected this box to an A.C. voltage source and found that the current through the box lagged the voltage by 90°, we would immediately say that the box acted like a coil. As far as the A.C. voltage source is concerned, this box is behaving as an inductance.

When we increase the inductance of an ordinary coil, the reactance of the coil increases and as a result, the current through the coil is reduced. In other words, if the coil draws a low current, it has a high inductance; if the coil draws a high current, it has a low inductance. If, now, our imaginary box draws a high current which

lags the voltage by 90°, we would say that this box has a low inductance; if the box draws a low current, we would say that it has a high inductance. You will soon see that we can consider the oscillator control circuit as an imaginary box having two terminals which are connected across one of the coils in the oscillator resonant circuit.

Now let us review a few fundamental facts about coils. When one coil is connected in parallel with the other, the inductance of the combination is less than that of either coil. Increasing the inductance of one of these coils increases the inductance of the combination, and likewise, decreasing the inductance of one coil decreases the inductance of the combination. An increase in inductance lowers the resonant frequency of a resonant circuit; a decrease in inductance increases the resonant frequency.

General Analysis of Oscillator Control Circuits. Now we are ready to investigate the behavior of the oscillator control circuit, to see how the D.C. control voltage produced by the discriminator can make this circuit act like an inductance and can change its effective inductance to correct for errors in tuning. A typical oscillator control circuit, along with the special superheterodyne oscillator circuit upon which it acts, is shown in Fig. *19A*.

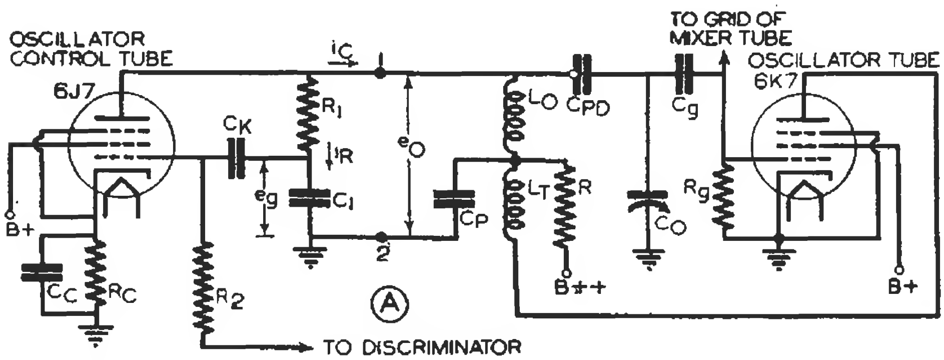


FIG. 19A. **Conventional oscillator control circuit (to the left of points *1* and *2*) and receiver oscillator circuit which it controls (to the right of points *1* and *2*).**

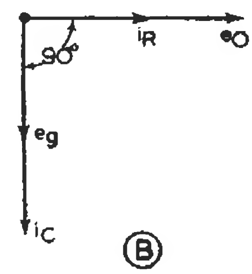


FIG. 19B. Vector diagram for oscillator control circuit.

Note that the D.C. control voltage produced by the discriminator is applied to the control grid of the type 6J7 oscillator control tube through resistor R_2. This D.C. control voltage, acting in series with the automatic C bias voltage produced by C_C and R_C, determines the average D.C. plate current for the oscillator control tube. Turning now to the oscillator circuit, coil L_O and tuning condenser section C_O form the oscillator tuned circuit, with trimmer condenser C_{PD} serving as the oscillator padder. Condenser C_g is the R.F. grid coupling condenser, and serves together with R_g to produce the rectified D.C. grid voltage for the 6K7 oscillator tube. Coil L_T is connected between the plate and grid circuits of the oscillator, and therefore provides feed-back; the upper end of this coil is grounded for R.F. current through by-pass condenser C_P. The oscillator tube receives its D.C. plate voltage through feed-back coil L_T, while the oscillator control tube receives its D.C. plate voltage through oscillator tank coil L_O.

Resistor R_1 and condenser C_1 in the oscillator control circuit are connected directly across the oscillator coil L_O in so far as R.F. currents are concerned, and form what is known as the *phase-shifting network.* This network receives the full R.F. voltage developed by the oscillator circuit, for C_P is an R.F. by-pass condenser. The resist-

ance of R_1 is so much greater than the reactance of condenser C_1 that we can consider this phase-shifting network as essentially a resistance. This means that the oscillator coil voltage e_O will send through R_1 and C_1 an R.F. current i_R which is essentially in phase with e_O.

Let us again resort to vector diagrams, to avoid the need for keeping phase relationships in mind while studying the circuit. We will use e_O as our reference vector, and it is therefore drawn as shown in Fig. *19B*. Vector i_R can now be placed, also along the reference line since it is in phase with e_O.

The flow of R.F. current i_R through C_1 develops across this condenser an R.F. voltage e_g which lags i_R by 90° (see diagram *L* in Chart *1*). We therefore draw vector e_g lagging behind i_R by 90°. This R.F. voltage e_g is applied to the control grid of the oscillator control tube through D.C. blocking condenser C_K, causing A.C. plate current i_O to flow through the oscillator control tube. This plate current will be in phase with the A.C. grid voltage, for this is a conventional amplifier circuit action in which a positive increase in the grid input voltage results in an increase in the plate current. We therefore draw vector i_O in phase with vector e_g, as in Fig. *19B*. Our vector diagram now shows clearly that R.F. current i_O lags oscillator coil voltage e_O by 90°. If we consider that part of the circuit to the left of points *1* and *2* in Fig. *19A* as a device having two terminals, we can readily see that the current i_O which is drawn by this device will lag by 90° the voltage e_O which is applied to the device. We have thus shown that the oscillator control circuit acts as an inductance shunting the oscillator coil L_O.

Now let us see how the D.C. control voltage produced by the discriminator will affect the value of this inductance shunting L_O. If the D.C. control voltage which is applied to the grid of the oscillator control tube through R_2 is positive with respect to ground, the net bias on this grid will become less negative, increasing the D.C. plate current of the oscillator control tube. Since this 6J7 tube is operated on the curved portion of its E_g-I_p characteristic curve, the increase in D.C. plate current produced by a positive D.C. control voltage moves the operating point for the tube to a steeper portion of the E_g-I_p characteristic. This means that a given A.C. voltage e_O on the grid of the tube will produce a larger A.C. plate current i_O, making this stage act as a smaller inductance. If the D.C. control voltage is negative, the net C bias voltage on the 6J7 tube becomes more negative. This shifts the operating point nearer to plate current cut-off, and e_O produces a low A.C. plate current, making this stage act as a larger inductance. Clearly, *the D.C. control voltage produced by the discriminator* serves to change the effective inductance of the oscillator control circuit.

Now, for the first time, we can consider the action of the entire A.F.C. system. When the receiver is properly tuned, so that the I.F. signal frequency corresponds to the resonant frequency of the discriminator resonant circuit, no D.C. control voltage is produced by the discriminator and the only C bias acting upon the oscillator control tube is that produced by C_O and R_O. This bias sets the operating point for the tube at a point which allows a medium value of A.C. plate current i_O to flow. The inductance corresponding to this A.C. plate current, acting in shunt with the oscillator inductance L_O, has been allowed for in the design of the oscillator, and consequently the A.F.C. system can

be considered inactive when the receiver is properly tuned.

When tuning is such that the I.F. signal frequency is below the I.F. value of the receiver, the discriminator produces a positive D.C. control voltage which increases the A.C. plate current and decreases the inductance effect of the oscillator control tube, thereby decreasing the shunt inductance across the oscillator tank coil and increasing the oscillator frequency.

When the I.F. signal frequency is higher than the correct value for the I.F. amplifier, the discriminator will produce a negative D.C. control voltage which makes the net negative C bias on the oscillator control tube more negative. The result is a decrease in A.C. plate current i_O; this corresponds to an increase in the effective inductance shunting oscillator inductance L_O, and this action of course lowers the oscillator frequency just enough to compensate for incorrect tuning.

The A.F.C. system cannot correct completely for errors in tuning, for then there would be no D.C. control voltage for correction purposes. The response of the I.F. amplier is always broad enough to allow for small errors in tuning, however, and consequently the A.F.C. action is satisfactory for all practical purposes.

Typical A.F.C. Circuits

Although the circuits in Figs. *15* and *19* have given the basic principles of A.F.C. systems, you will find a great many variations of these circuits. Before analyzing a number of typical circuits to familiarize you with these variations, let us consider briefly those components of each section which are to be found in all A.F.C. systems.

The discriminator section can be identified on the circuit diagram of a receiver having A.F.C. by the fact that it will have *a double-diode vacuum tube, with the two diode plates connected into a tuned circuit having a split or center-tapped coil which is fed with the I.F. amplifier output voltage both inductively and by a direct connection to the center tap.* Each diode section thus gets two distinct I.F. voltages: *1,* half of the I.F. output voltage of this resonant circuit; *2,* the I.F. amplifier output voltage. The phase relationship between the voltages determines what the resultant I.F. voltage acting on each diode section will be.

In general, the oscillator control tube will have C bias voltages produced by two different sources: *1,* by a cathode circuit resistor; *2,* by the discriminator, feeding through a resistance-capacitance filter which keeps out R.F. components. Furthermore, the oscillator control circuit will have a phase-shifting network, usually made up of a resistor in series with a condenser, the combination being in shunt with the coil of the oscillator resonant circuit. The condenser in this phase-shifting network will have a very low capacity, ordinarily from about 2 mmfd. to 20 mmfd. Occasionally the grid-to-cathode inter-electrode capacity of the oscillator control tube will be used in place of a separate phase-shifting condenser.

With these general ideas in mind, we are ready to consider a few of the unique variations of the basic A.F.C. circuit just studied.

General Electric A.F.C. System. In Fig. *20* is shown the circuit diagram of the A.F.C. system and associated circuits used in General Electric Models E-101, E-105 and E-106 all-wave superheterodyne receivers. The A.F.C. system follows very closely the fundamental circuit presented in Figs. *15* and *19,* except that the discriminator in this General Electric

circuit also serves as second detector and A.V.C. tube.

The output of the I.F. amplifier feeds into the discriminator circuit, through a conventional split-secondary I.F. transformer with which you are already familiar (Fig. *15*). Notice, however, that the resistor between the cathodes of the double-diode tube is divided into three sections rather than two. Point *2* is the of low voltage rating, which provides an entirely satisfactory ground for I.F. and A.F. signals. The use of this condenser permits connecting point *1* through a 100,000-ohm resistor to a —3 volt terminal in the power pack voltage divider. In this way all A.V.C.-controlled tubes in the receiver get an initial C bias of —3 volts, eliminating the need for automatic C bias resistors in some of the

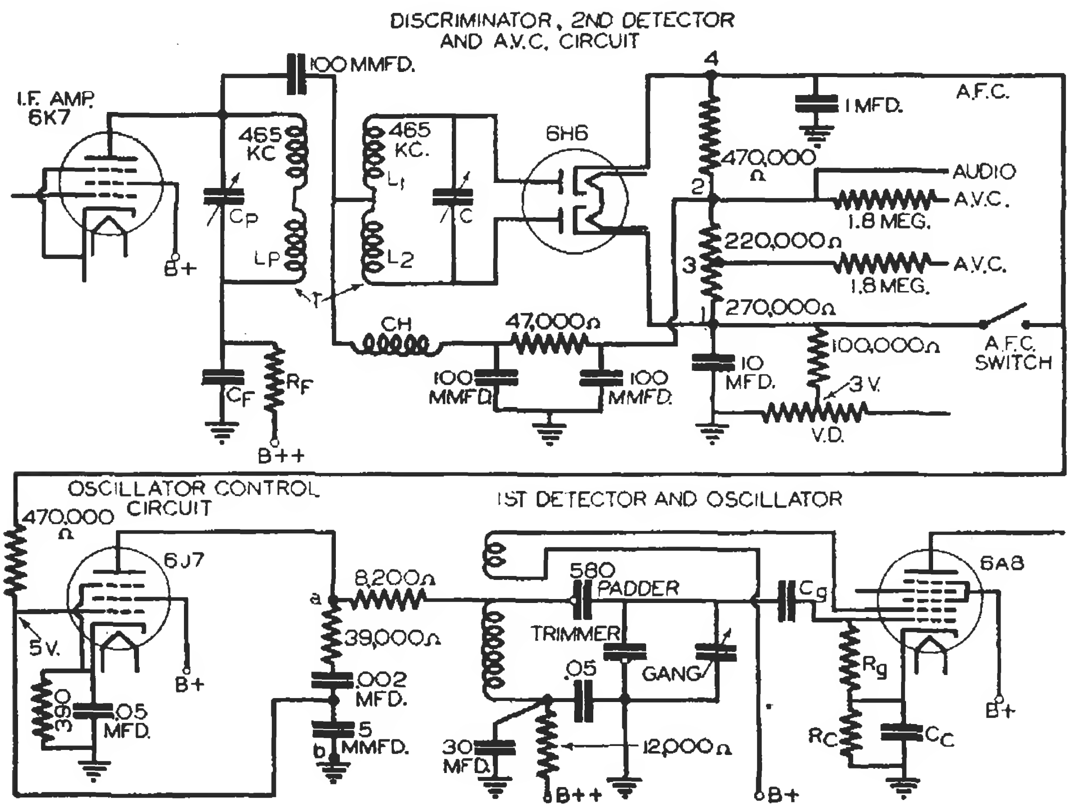


FIG. 20. Circuit diagram of the A.F.C. system used in General Electric Models E101, E105 and E106 receivers.

midpoint of this resistor network. Between this point and the upper cathode (point *4*) is a 470,000-ohm load resistor, while between point *2* and point *1*, the lower cathode, is a 220,000-ohm resistor in series with a 270,000-ohm unit, these together being approximately equal to the 470,000-ohm resistor. The tap at point *3* serves to provide a lower A.V.C. voltage for one or more of the A.V.C.-controlled stages in the receiver.

Ordinarily we would expect the circuit to be grounded to the chassis at point *1;* instead, however, it is grounded through a 10 mfd. condenser cathode circuits. The 100,000-ohm resistor and 10 mfd. condenser also serve to keep power pack hum out of the discriminator circuit.

The cathode of the upper diode section is grounded through a 1 mfd. condenser, and the cathodes of both diode sections are therefore at ground R.F. potential. It is not essential that condensers of equal capacity be across each diode load resistor. The A.V.C. sources feed through 1.8-megohm A.V.C. filter resistors.

A resistance filter made up of two 100 mmfd. condensers and a 47,000-ohm resistor is placed between point

2 and choke coil *CH* in order to place point *2* at ground potential for I.F. currents. These two condensers are not large enough to by-pass any audio currents to ground, but they do serve to keep I.F. currents out of the audio circuit.

Now locate the A.F.C. switch in the discriminator circuit. When this switch is closed, the A.F.C. voltage developed between point *4* and point *1* is shorted out, and no D.C. control voltage is applied to the oscillator control tube. The receiver now behaves like any ordinary superheterodyne receiver not having A.F.C. At first glance, one might believe that the A.F.C. switch also shorts out the A.F. and A.V.C. voltages; actually, however, the discriminator circuit becomes a full-wave detector, as shown in Fig. *21*, when the switch is closed. With this connection, one diode will rectify one-half of each cycle of the I.F. signal, and the other diode will rectify the other half of each cycle. Both half-wave rectified currents are fed through the same parallel resistors, thus providing full-wave rectified voltages across these resistors.

The 1-mfd. condenser between point *4* and ground acts with the diode load resistors as a time delay which prevents immediate building up of the D.C. control voltage produced by the discriminator. The duration of this time delay is purposely made longer than the A.V.C. time delay, in order that the I.F. signal delivered to the input of the discriminator will reach its final value before A.F.C. circuit action begins. This is necessary because the D.C. control voltage produced by the discriminator is dependent upon the intensity of the I.F. signal as well as upon the amount by which it is off resonance (the greater the intensity of the I.F. signal, the greater will be the D.C. control voltage available for correcting mistakes in tuning, and consequently the A.F.C. system will be able to pull in strong stations even though the tuning dial setting may be considerably off from its correct value for that station).

The D.C. control voltage produced by the discriminator in Fig. *20* is fed to the control grid of the oscillator

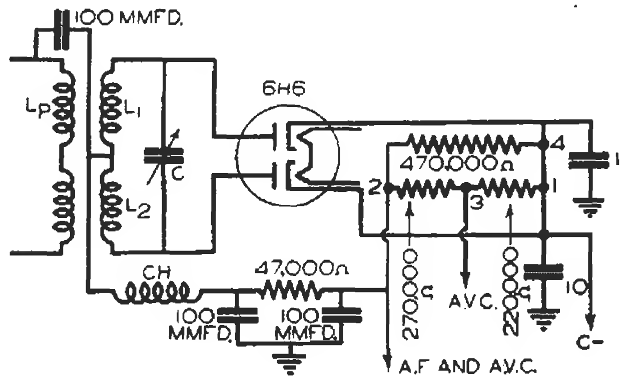


FIG. 21. When the A.F.C. switch in the circuit of Fig. *20* is closed, the discriminator circuit is transformed into the conventional full-wave detector circuit shown here.

control tube through a 470,000-ohm circuit-isolating resistor. The parts between points *a* and *b* in the oscillator control circuit form the phase-shifting network. A .002-mfd. condenser is inserted between the customary resistor and phase-shifting condenser to prevent the D.C. plate supply source from acting upon the control grid of the oscillator control tube. This extra condenser has negligible reactance at R.F. signal frequencies, and therefore serves merely as a D.C. blocking condenser.

The oscillator control circuit to the left of points *a* and *b* acts as an inductance whose value depends upon the polarity and magnitude of the D.C. control voltage provided by the discriminator; thus effective inductance is shunted across the coil in the oscillator resonant circuit, the circuit being through a 30 mfd. condenser which serves as a D.C. blocking condenser, and through an 8,200-ohm resistor which has the effect of equalizing over the entire tuning range of the receiver the amount of shunt induc-

tance applied to the oscillator resonant circuit.

With these facts in mind, you should have no difficulty in completing an analysis of this General Electric A.F.C. system. It reacts in exactly the same way as the circuits in Figs. *15* and *19* to I.F. signals which are above or below the I.F. value of the receiver.

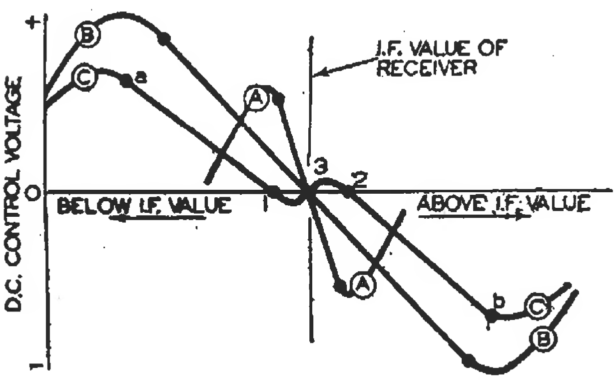


FIG. 22. Types of S-curves obtained with discriminator transformers having various degrees of coupling.

Discriminator Transformer Design Problems. The conventional discriminator transformer used in the circuits of Figs. *15* and *20* require careful design. Weak coupling between the primary winding and the split secondary winding makes these two tuned circuits highly selective, giving the S-curve marked *A* in Fig. *22*. The steepness of the linear region of this curve indicates that stations will be pulled in very close to the I.F. value (to point *3*); the small frequency difference between the ends of the linear region means that manual tuning must be quite accurate before A.F.C. will take hold, and the relatively low magnitudes of D.C. control voltages provided by curve *A* may not be sufficient for full correction.

Approximately critical coupling gives S-curve *B*, indicating greater D.C. control voltages and a greater frequency range over which A.F.C. will pull in a station; in fact, the linear range may be too wide, allowing an undesired station to be dragged over an adjacent desired station. The linear section of the curve is less steep, indicating that A.F.C. will not correct as completely as with curve *A*, but a deviation of a few hundred cycles from resonance is ordinarily quite permissible.

When coupling is greater than the critical value, the two tuned circuits interact, giving a double-peak response curve which results in the undesirable S-curve at *C* in Fig. *22*. This curve tells us that I.F. signals which are outside of the region between points *1* and *2* will be pulled in to a frequency corresponding to these points rather than to the correct I.F. value at point 3.

The curves in Fig. *22* show clearly that the design of a discriminator transformer must be a compromise between the various desired performance characteristics. In addition, the receiver must have a good A.V.C. system, in order that signals which are received at different signal levels will produce almost identical voltages in the discriminator circuit. If this were not true the amount of correction provided for mistuning would vary with the strength of the signal picked up.

Silvertone (*Sears Roebuck*) *A.F.C. System.* The manufacturers of Silvertone receivers, as well as a number of other manufacturers, have overcome these discriminator transformer design problems by using a triple-tuned circuit ahead of the discriminator, as shown in Fig. *23*. The three resonant circuits, L_1-C_1, L_2-L_M-C_2, and L_3-L_4-C_3 are all peak-tuned to the I.F. value of the receiver. Circuit L_3-L_4-C_3 is designed with the correct Q factor to give the desired S characteristic, and the coupling between L_M and L_3-L_4 is made close enough to give the required voltages across L_3 and L_4 for the diode sections.

Another unique feature of this Silvertone A.F.C. system is the absence of the choke coil ordinarily found between points *1* and *2*. In this particular circuit the choke coil is unnecessary because the required voltage is developed by the middle resonant circuit (L_2-C_2-L_M) which is directly connected between points *1* and *2*. Point *2*, being negative with respect to ground and having a potential which is proportional to the rectified current flowing through the lower diode load resistor, serves as the A.V.C. terminal. The 1-megohm resistor and .05 mfd. condenser make up the A.V.C. filter which removes A.F. and I.F. components from the A.V.C. voltage and at the same time determines the time constant of the A.V.C. system. Point *2* also serves as the A.F. voltage supply terminal, with the .05 megohm resistor and the two .00025 mfd. condensers keeping I.F. signals out of the audio amplifier. Terminal *3* on the diode load resistor network is, of course, the point from which the D.C. control voltage for A.F.C. purposes is fed into the oscillator control circuit. The connection is through a 1-megohm resistor and .1 mfd. condenser which serve as the A.F.C. filter. The time constant of this filter is greater than that of the A.V.C. filter, as is required.

The oscillator control circuit in Fig. *23* is of conventional design, with R_N and C_N serving as the phase-shifting network. The receiver oscillator is of the tuned plate type, with the phase-shifting network shunting the oscillator tuning coil.

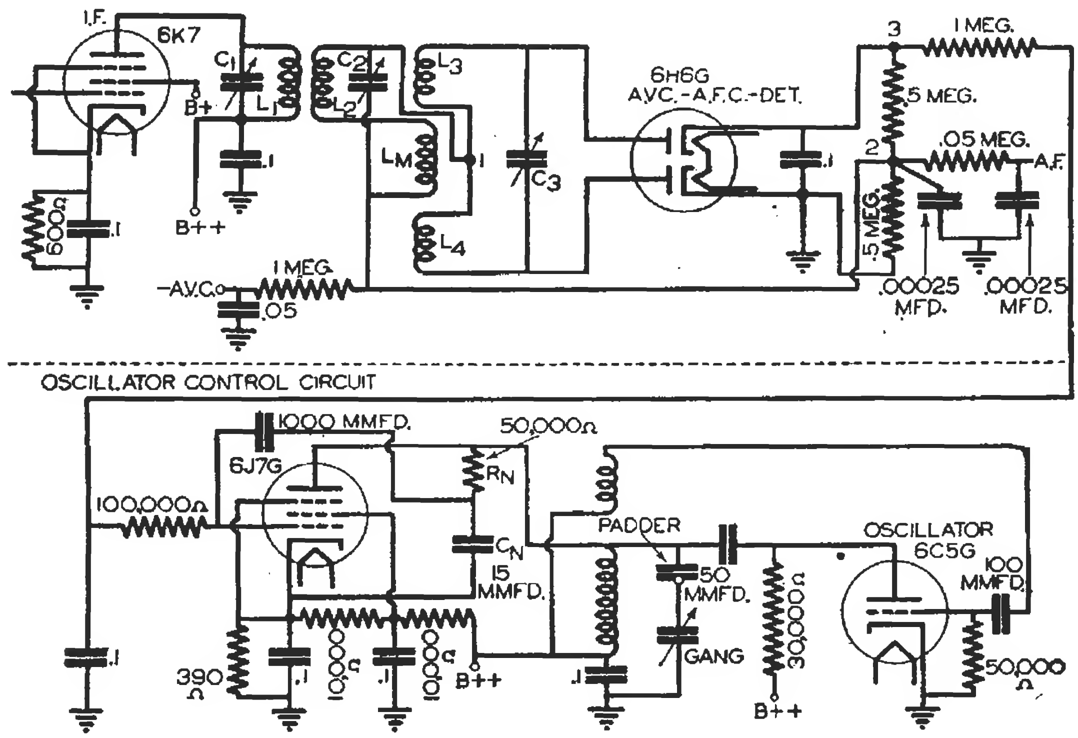


FIG. 23. Circuit diagram of the A.F.C. system used in the Silvertone model 4587 receiver.

A somewhat similar discrimination circuit is also used in one RCA A.F.C. system; the essential difference between the RCA and Silvertone circuits is shown in Fig *24*. The first two tuned circuits in the discriminator transformer are the same in both cases, the difference being in the third tuned circuit. Note that in Fig. *24* coil L_M induces a voltage in the split-coil arrangement L_3-L_4, rather than in two separate coils as was the case in Fig. *23*. Across L_3-L_4 is fixed condenser C_3 and variable inductance L, having an iron dust core whose position can be varied in order to change

the inductance of L and tune the discriminator circuit. Coil section L_3 also has an adjustable iron dust core which can be adjusted during alignment of the receiver to make the inductance of L_3 exactly equal to the inductance of L_4 and thus make both coils develop the same I.F. voltage for the diode section.

Effect of Preselector Upon A.F.C. Action. Up to this point we have neglected the effects of the preselector upon the action of the A.F.C. system. Actually, however, the selectivity of the preselector is quite important with relation to that characteristic of an A.F.C. system which is known as "dragging." Consider, for example, a receiver having an S curve which indicates the ability to correct for signals as much as 5 kc. off tune. When a station is properly tuned in, then gradually tuned off resonance, the A.F.C. circuit will correct the oscillator frequency satisfactorily for about 5 kc. off resonance. Tuning farther off than this does not remove the discriminator control voltage entirely, as you can see by referring to the S curve in Fig. *18;* actually the D.C. control voltage may be produced for a considerably greater deviation from resonance, but it will be insufficient to correct completely for the off-tune condition. This action of an A.F.C. system in making a partial correction outside of the efficient operating range of the system is referred to by engineers as "dragging."

When two stations are close together in frequency, and one of the stations is tuned in, it is perfectly possible that a receiver having A.F.C. and a broad preselector might not be able to pick up the other station. The station originally tuned in is held by the A.F.C. system because of excessive dragging action. With this broad preselector, the only way to hear the adjacent station would be to cut off temporarily the A.F.C. action of the receiver in order to allow the adjacent station signal to take hold of the A.F.C. system; a highly selective preselector, however, *would not allow* an A.F.C. system to hang onto a powerful local station when the receiver is tuned to a weaker adjacent station.

Here is another interesting result of dragging action; when a receiver having A.F.C. is tuned carelessly to a desired weak station, so that the desired signal is being dragged in from a position considerably off tune, any fading of this desired signal may allow an adjacent station to take hold.

The remedy for excessive dragging involves improving the selectivity of the preselector enough so that when the tuning condensers are outside the desired range of A.F.C. action, the reduction in R.F. gain will reduce the I.F. signal enough to make the discriminator release its control over the oscillator control tube. Strictly speaking, the preselector should be band-passed so it will tune broadly in the frequency range over which A.F.C. is to act, but will have a sudden reduction in gain (high selectivity) immediately outside of this band-pass region.

Band-pass preselectors are rarely used in receivers, but sufficient selectivity should be incorporated in the preselector to prevent annoying dragging action. Because it is not easy to get high preselector selectivity in the high frequency bands of an all-wave receiver, A.F.C. action is often omitted in these bands. Any A.F.C. circuit is most effective for strong stations in the broadcast band.

Philco Push-Pull A.F.C. System. The automatic frequency control system used in some Philco receivers is unique in that when the receiver is properly tuned or the A.F.C. system is shorted out, the receiver oscillator circuit is entirely independent of the

A.F.C. system. It is therefore possible to align the oscillator and preselector independently of the A.F.C. system, whereas in the systems previously described the shunt inductance of the oscillator control tube always had to be considered when aligning the oscillator trimmer condensers.

A typical example of this unique Philco push-pull A.F.C. system, that used in the Philco model 37-9 all-wave superheterodyne receiver, is shown in Fig. *25;* it is also known as a *magnetic tuning system.* As you can see, the type 6K7G tube in the final I.F. amplifier stage feeds into two entirely separate circuits, a 6Q7G second detector-A.V.C.-first A.F. tube circuit (not shown) and the conventional 6H6G double-diode discriminator circuit.

The two diode sections of the discriminator tube each receive two I.F. voltages in the usual manner; the I.F. voltage existing across the tuned plate circuit of the 6K7G tube is applied between the center tap of the split secondary winding and the cathodes of the 6H6G tube, and the I.F. currents flowing in the split secondary (due to the voltage induced by current in the tuned plate circuit) produce across the coil sections the other I.F. voltage acting on each diode section. The resulting rectified current flow develops the required D.C. discriminator control voltage across the two 2-megohm resistors connected between the cathodes. The polarity of this voltage depends, of course, upon whether the I.F. signal frequency is above or below the correct value, and the magnitude of this D.C. voltage depends upon the amount of error in tuning. This D.C. control voltage is applied across two 1-megohm resistors having their midpoint grounded, and hence points x and y will *always* be equal to each other in potential and of opposite polarity *with respect to ground.* In this manner the discriminator output voltage is divided into two equal voltages of opposite polarity.

During off-tune conditions these equal and opposite voltages at x and y are fed to points a and b, at the input of the oscillator control tube. Note that there is a 490,000-ohm re-

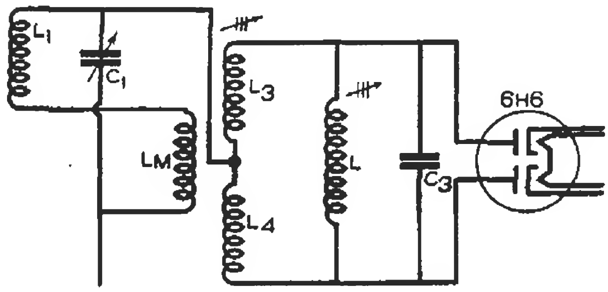


FIG. 24. Discriminator transformer connections used in RCA model 812K receiver.

sistor in each lead, with a .3 mfd. condenser shunted across the leads; these filters serve to remove all I.F. and A.F. signal components and at the same time delay the discriminator action enough to make it slower than A.V.C. action. The two .15 mfd. condensers with common terminals grounded serve to maintain a balance between the filtered A.C. currents. Switch SW_1 is the A.F.C. ON-OFF switch; when in the OFF position it grounds points a and b. Switch SW_2 closes only when the dial tuning mechanism is operated, and shorts points a and b to prevent A.F.C. from dragging one station beyond the dial setting for another station.

Observe now that a type 6A8G pentagrid converter tube serves as the first detector-mixer-oscillator tube for the receiver, with the first grid serving as the oscillator control grid and the second grid acting as the oscillator plate. The oscillator tuned circuit, made up of L_1, C_1, C_3 and the 85-ohm resistor, is connected between the first grid and the chassis. The necessary feed-back is obtained by connecting the oscillator plate electrode through a 250-mmfd. condenser to the

lower end of coil L_1; current flow through this section of L_1 induces the feed-back voltage in the main section of L_1. C_3 serves as the oscillator low frequency padder and C_2 as the high frequency trimmer. Rectified grid current flowing through L_1 and a 32,000-ohm resistor in the oscillator tuned circuit produces across this re-

into the discriminator circuit. This R.F. voltage e_R produces R.F. plate currents i_2 and i_3 which are *in phase* with e_R, are equal in value when both tube sections have the same C bias voltage, and flow in opposite directions through the two halves (L_2 and L_3) of the secondary winding of the oscillator control transformer.

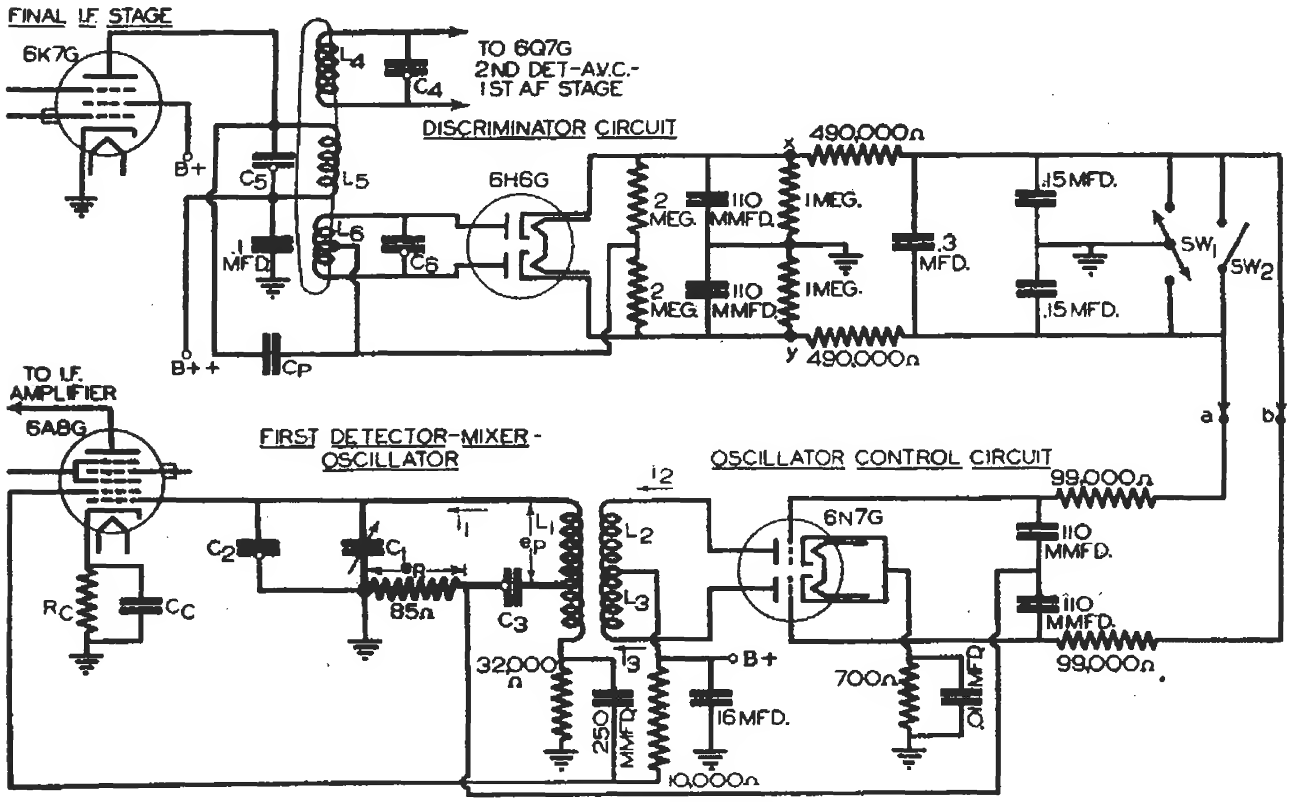


FIG. 25. Circuit diagram of the push-pull A.F.C. system (also known as magnetic tuning) used for the broadcast band on the Philco model 37-9 all-wave receiver. There is no A.F.C. action on short-wave bands in this set.

sistor a self-adjusting negative C bias which acts in series with the fixed C bias produced by the oscillator cathode resistor.

Locate the oscillator tuned circuit, shown in heavy lines in Fig. *25* and made up essentially of L_1, C_1, C_3 and an 85-ohm resistor. The same R.F. current i_1 flows through all of these parts, developing across the 85-ohm resistor an R.F. voltage e_R which is in phase with the current.

R.F. voltage e_R is applied to the two control grids of the 6N7G oscillator control tube through 110 mmfd. condensers. Note that 99,000-ohm resistors connected to these grid leads prevent the R.F. voltage from feeding

From your study of coils you will recall that increasing the amount of flux through a coil increases its inductance, and decreasing the flux lowers the inductance. If current i_2 flowing through L_2 produces a flux which *increases* (aids) the flux produced by i_1 through L_1, then i_3 flowing in the opposite direction through L_3 will produce a flux which *decreases* (opposes) the flux produced by i_1 through L_1. (This holds true only when all three flux-producing currents are *in phase,* as they are in this circuit.) Current i_2 thus has the effect of increasing the inductance of L_1 in the oscillator tuned circuit, while i_3 decreases the inductance of L_1.

When i_2 and i_3 are equal, their effects upon the inductance of L_1 will be equal and will cancel each other. This proves clearly that when the A.F.C. system is inoperative, or when the receiver is properly tuned, *the oscillator control tube has no effect whatsoever upon the oscillator tuned circuit.*

moving the operating point to a less steep region and reducing the A.C. plate current for that section. The D.C. control voltage thus makes i_2 different from i_3. The effects of the larger current upon the inductance of L_1 are not altogether cancelled out by the effects of the smaller current; the result is a net change in the inductance of L_1, and this changes the frequency of the oscillator. In other words, one current *pushes* up and the other *pulls* down the inductance of L_1.

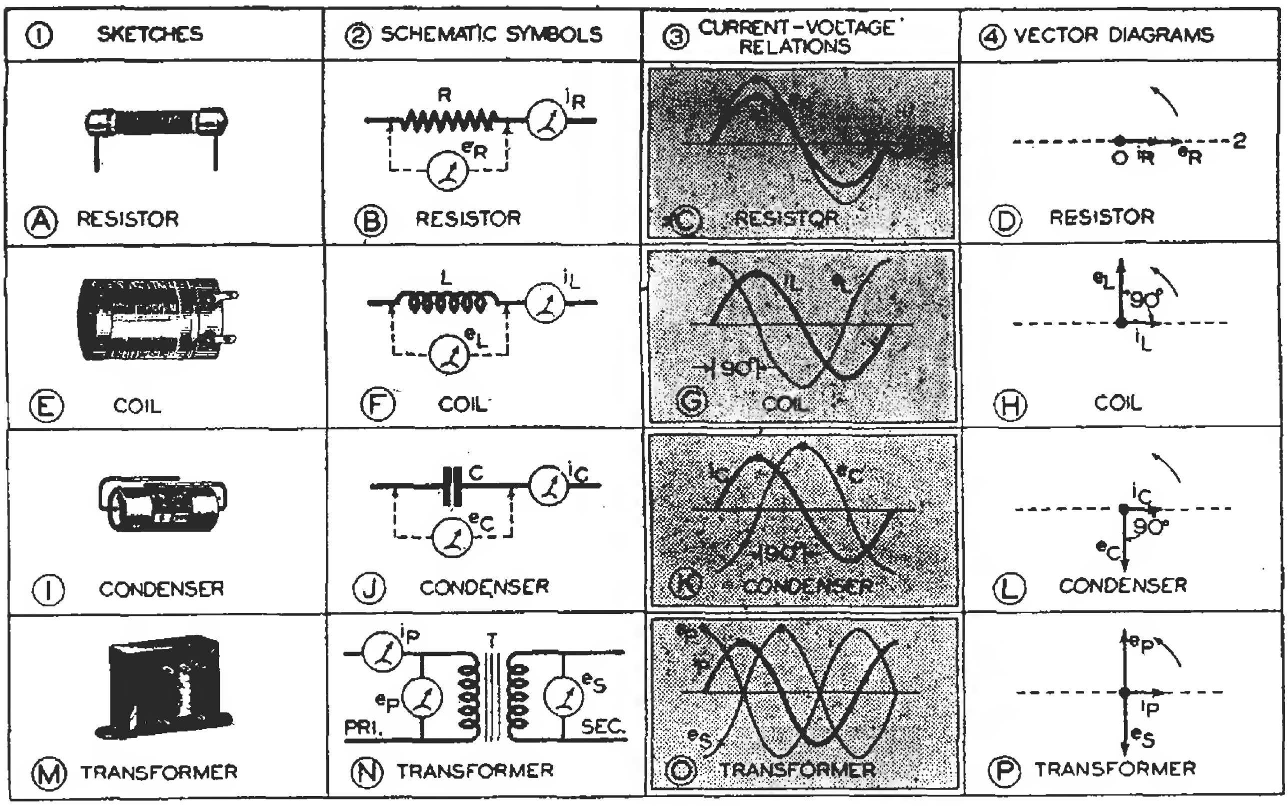


CHART 1. **This chart gives you important facts about the phase relationships of voltages and currents for resistors, coils, condensers, and transformers in A.C. circuits.**

As you already know, improper tuning of a receiver causes D.C. voltages of equal value but opposite polarity with respect to ground to be developed by the discriminator; these are applied to the grids of the 6N7G oscillator control tube through 99,000-ohm resistors, making one grid less negative and the other more negative than the bias value determined by the 700-ohm cathode resistor. Making the net C bias of one triode section less negative moves the operating point on the E_g-I_p characteristic to a steeper region, increasing the *A.C.* plate current for that section; at the same time the net C bias on the other triode section becomes more negative,

The manner in which leads *a* and *b* are connected to the control grids of the 6N7G tube determines whether this control will be in the proper direction; if the control is such as to exaggerate errors in tuning, reversing the leads will correct the trouble.

Adjusting A.F.C. Systems

Fortunately for Radiotricians, the adjustment of an A.F.C. system is quite simple. The only instruments needed are an ordinary signal generator capable of producing the I.F.

value of the receiver, and a sensitive low-range (0-10 volts) voltmeter. At least a 5,000 ohms-per-volt meter should be used; if this is not available, use an ordinary vacuum tube voltmeter or one which you assemble yourself from a type 31 tube and batteries, using a milliammeter as the indicator.

The signal generator is set at the I.F. value of the receiver and is connected to the input of the I.F. amplifier. The sensitive voltmeter is connected across the D.C. output terminals of the discriminator (points *1* and *4* in Fig. *20;* between the chassis and point *3* in Fig. *23;* between points *a* and *b* in Fig. *25*). The I.F. amplifier stages are now aligned in the usual manner for a maximum reading of the voltmeter. (Do not touch the trimmer across the split secondary of the discriminator stage at this time unless the voltmeter deflection is too small for an accurate adjustment; in this case, adjust the trimmer in either direction just enough to get a suitable deflection.) When adjusting the tuned circuit ahead of this split secondary winding, it is a good plan to move the signal generator to the input of the previous tube; adjust this discriminator input circuit carefully for maximum output.

Now, without changing the voltmeter or signal generator connections, adjust the trimmer condenser in the split coil circuit for *zero meter reading*. This adjustment is quite critical, so be sure that the minimum reading is secured when the adjusting tool is removed. This is all there is to the adjustment of a conventional A.F.C. circuit.

You might think that with so simple an adjusting procedure, the information given in the first part of this lesson is unnecessary for the practical man. This is decidedly not true, however, for an understanding of how A.F.C. systems work is quite necessary when trouble develops due to failure of various parts in the system. If your work will involve the servicing of receivers having automatic frequency control, you will at some time or other find use for every bit of the information given in this lesson.